

Astrometry from Mutual Phenomena
of the Galilean Satellites in 1990-1991

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I. Introduction

The first extensive photometric observations of the mutual eclipses and occultations of the Galilean satellites date back to Jupiter's 1973 apparition. Since that time, at every six year opportunity, such observations have been continued and improved. Our most recent contribution (GSO, 1991) concentrated on satellite astrometry, deriving separations between satellites from nearly 200 light curves observed during the 1985 season. The present paper continues this tradition [see references in GSO (1991)] by obtaining astrometry from 213 light curves observed during 1990-1992. There are, however, three new aspects to this paper. First, we wish to mention that some 80% of the data reduced here has been collected and helpfully placed on the WEB by the staff of the Bureau des longitudes [<http://www.bdl.fr>] so as to be widely available. We greatly appreciate this service. The other forty curves were either observed by or communicated to us and will

also soon be available at the above address. Second, we redeem a pledge made in GSO (1991) by comparing its results--as well as those derived here--with the widely used satellite ephemerides, E3 and E5, constructed by Lieske (1998 and its references). Figures 1-6 discussed in the last section provide these comparisons. Finally, in the opening paragraphs of the next section, we need to revisit problems raised by phase corrections so as to provide a clear and verified prescription for handling past and present data.

II. Review of Reduction Procedures; the 1991 Data

First, a bit of history: It has been our plan to present the results derived from mutual event observations over the four "seasons", 1973, 1979, 1985 and 1991 as a completely self-consistent body. Any search for secular effects in Io's motion in particular sets this requirement. Improved observational methods, particularly with regard to timing, has meant that the quality of the data obtained during the two most recent apparitions is some-

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what superior to the first two. Reduction procedures have also been improved and corrected and it is to that topic that we wish to turn attention now. Our aim in analyzing the mutual events is to provide a tabulation of relative positions of the geometric centers of two satellites at a specified time. An obvious candidate for the latter is the light curve midtime. However, this observed time corresponds to the separation between the geometric center of the eclipsing or occulting satellite and the light center of the eclipsed [occulted] satellite. The introduction of phase corrections is a standard technique whereby the geometric center of a body at a gibbous phase can be recovered from photometry. Thus the proper use of phase corrections would lead to the desired goal of yielding separations of the satellites' geometric centers at midevent.

The nature and magnitude of the phase corrections needed to account for

the small systematic effects shown in the analysis of the 1973 data (Aksnes and Franklin, 1976) were finally discussed and calculated by Aksnes et al. (1986). They showed that correcting for phase effects could be done either by altering the relative satellite positions at given time [e.g., the midtime] or, equally well, by applying the appropriate change to the midtime itself. Because the 1973-79 positions had already been published, that paper followed the second option and provided a set of time corrections, DT, to all the earlier tabulated material. It was our intent in reducing the 1985 data to present in Table I of GSO (1991) a listing that incorporated the phase corrections internally so that the given astrometric offsets would correspond to geometric center separations at the listed midtimes. In preparing the present paper and checking offsets against the E3 and E5 ephemerides, it became clear that the small phase corrections used in GSO were correct in magnitude but had been applied to the satellite separations in right ascension and declination with the opposite sign. This sign error remained undetected in GSO (1991) because our checking then was based on the

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run of longitude and latitude corrections [Dx and Dz] which had been properly phase corrected. By a happy turn of events, however, we had also provided in the GSO table the time corrections, DT. That fortunate inclusion means that the error can be removed and correct results recovered by adding DT twice to the times given in GSO Table I, column 2. We have carefully checked in every way we are aware of that this procedure is correct. We do regret any confusion that has been caused.

Now to the present: Since some of the 1991 data had already been reduced before we noticed the error, we have elected to rely in this paper on changing the observed midtimes by adding the "2DT" correction to all entries. Thus the header on col 2 reads "CtdTime" [in UTC], i. e., "corrected time", rather than midtime, to reflect this policy. Since Table I also provides the DT correction itself in col 3, midtimes, should they be of interest, can be obtained by subtracting 2DT from col 2. At the risk of being redundant, we include here a general prescription for handling all of our published mutual event data:

data year	reference	method
1973	Aksnes and Franklin (1976)	add DT tabulated in Aksnes et
1979	Aksnes et al. (1984)	al. (1986) to all midtimes
1985	GSO (1991)	DT's are given in that paper; add 2DT to listed midtimes
1991	this paper	use cols 2, 6 and 7 as given

In most ways Table I of this paper is in the same format as Table I of GSO (1991), a fact that allows us to compress the following description. More information regarding instrumental details, techniques and location of

the observing stations which are abbreviated in col. 1, are accessible at the Bureau des longitude's WEB site mentioned earlier. The second part of col. 1 labelled "date" gives first the day and then the month of 1991--except

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for the few 2e/o3 events that occurred in Nov. and Dec., 1990 and the two others in March, 1992. [Europa's inclination of nearly 0.5 deg is responsible for events taking place at times somewhat displaced from when the earth or sun passes through the Jovian equatorial plane.]

We have again retained in cols. 4 and 5 the longitude and latitude corrections, Dx and Dz, to Sampson's (1921) theory. They allow an easy comparison with results at earlier apparitions, before a more precise theory

(cf Lieske, 1998) was developed, while also providing a helpful aid in tracking down spurious observations. Both corrections apply at the observed mid-times listed in col 8, which have been antedated to give the JED [ephemeris time] at Jupiter. Figure 4 plots the longitude corrections, Dx, for the extensive series of 2e/o1 events occurring in the early months of 1991. [Phase corrections have been applied; had they been absent--or wrong--systematic differences between the eclipses and occultations would be apparent.] Columns 6 and 7 provide separations in right ascension, DRA, and declination, DD, between two satellites at the time listed in col. 2. They are in the sense of eclipsed [occulted] satellite minus eclipsing [occulting] satellite and are heliocentric or geocentric displacements respectively.

Final columns list geocentric [occultations] and heliocentric [eclipses] orbital phase angles and weights calculated according to a simple formula discussed by Aksnes and Franklin (1976). Certain events listed in Table I--annular or total eclipses, for example--sometimes fail to provide accurate latitude corrections and it becomes necessary to impose a value derived from other considerations [cf GSO, 1991] on the solution. The appearance of Dz in parentheses marks these cases, which have also been assigned the lowest weight.

III. Accuracy of Results; Residuals

Normally, a Jovian apparition in which mutual events occur will in-

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clude a series of eclipses and occultations that extend over a considerable range of orbital phases for one satellite while the other remains much more closely confined. Such a sequence, because it is also likely to scan a range of solar phase angles, provides an important means of assessing accuracy, both of the observations and their theoretical representation. In 1985 two of these series were well-observed. The first involved eclipses and occultations of Europa by Ganymede whose residuals with respect to the E5 ephemeris are plotted in Figs. 1a and b. Figures 2a,b and 3

concentrate on the other series, showing residuals from both E3 and E5 for a set of events in which Io eclipsed and occulted Europa. A look at all the figures leads to the following comments. First, a comparison of Fig. 2a with 2b indicates that the E5 ephemeris represents an improvement by reducing the systematic nature of the right ascension residuals, while Figs. 6a and b argue that their average magnitude has lessened as well.

Second, scatter in the declination residuals is quite generally larger than is the case for those in right ascension [cf Figs. 1a,b; 5a,b], while the scatter in all residuals tends to be greater for events occurring closer to Jupiter. Both effects are ultimately the consequence of light scattered from the planet. The first effect can be traced directly to the higher precision of the relative longitude over latitude separations [i.e., in the Jovian equatorial plane and perpendicular to it] obtained from the light curve of an event, because the former depends on its timing and the latter on its amplitude. Especially for events near Jupiter, accurate measurement of scattered light can pose a vexing problem. CCD observations [see, for example, Mallama (1992)] were in part designed to address this question and they have made real progress toward achieving more accurate light curve am-

plitudes. Most observations, however, were not made with CCD's. Another effect reduces the accuracy of results derived from occultations vs [most] eclipses, particularly with regard to separations in declination, because the determination of their light curve amplitudes requires a measurement of

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satellite brightness ratios. Both the influence of scattered light and [some] uncertain brightness ratios have contributed to the larger scatter in the 1991 data [cf Figs. 5a,b,c] which were gathered from less homogeneous sources than was the case in 1985.

Since phase corrections have proved such a recurring issue, it is now of some comfort to see in all figures that there are no striking systematic differences between residuals--especially those in right ascension--generated from (a) eclipses and (b) occultations. The series in Fig. 1a follows 3e2 [open squares] and 3o2 events over solar phase angles from 0.5 deg. [that happened to occur when events were taking place at a longitude, λ , of Europa equal close to 80 deg.] out to 6.4 deg. near $\lambda = 100$ deg. Since phase corrections for eclipses and occultations are equal in magnitude but opposite in sign (Aksnes et al., 1986), their complete neglect would introduce a difference in the e/o residuals of 0.045 arc sec at 6.4 deg. A more extensively covered case is that of the 2e/o1 series of 1991 presented in two ways in Figs. 4 and 5a,b. In Fig. 5a, there seems to be the suggestion that the occultation residuals are larger in magnitude when Io's longitude lies near 270 deg. But since this position corresponds to opposition, any e/o difference cannot be the result of phase effects.

Figures 5a and c plot right ascension residuals measured with respect to the E5 and E3 ephemerides. The former have an average value close

to -0.05 arcsec, while the latter are far less constant over orbital phase angle and nearly twice as large. Their behavior raises an important question: do the residuals arise from unmodelled dynamical effects or from some photometric property of the satellite surfaces---albedo variations are

a likely example? In reviewing an earlier version of this paper, Jay Goguen kindly took the trouble to project an albedo map of Io derived by Alfred McEwen from the 1979 Voyager encounters to the viewing geometry of these 1991 2e/01 events. He concluded that an extensive bright region on Io would

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displace the satellite's photometric and geometric centers by about 130 km and so produce systematic right ascension residuals of about -0.043 arcsec. He found the corresponding residuals in declination to be $+0.026$ arcsec so that in both coordinates they lie close to the values apparent in Figs. 5a and b. Thus one interpretation of the '91 observations would claim that E5 represents the motion of the Galilean satellites (and of Io in particular) to the limit of observational accuracy. This possibility rests principally on the (uncheckable) assumption that Io's albedo variations were essentially the same in 1991 as they were in 1979. The alternative interpretation argues that E5 itself may need further revision, much as the earlier ephemerides in that series have. Some combination of these two is perhaps even more plausible.

It is unfortunate to have to leave the question of accuracy in this uncertain state. At present we can only offer several remarks, intended to be both clarifying and hopeful: 1) the great majority of the mutual event light curves of Io are (except in the infrared) completely symmetric---a consequence of the low resolution of small-to-moderate instruments---so that albedo variations do not appear to have made a marked contribution; 2) although a variable albedo will affect all types of satellite astrometry, mutual event observations seem to be particularly at risk. Eclipse timings of disappearance into or reappearance from Jupiter's shadow rely only upon a small limb segment of a satellite. Thus, although modelling limb darkening, among other concerns, is important, albedo variations are less so. The latter do affect photographic and CCD astrometry, but their influence would tend to be averaged out if the observations spanned a broad range of satellite longitudes. 3) a series of J1e/0J2 events similar in extent to the 2e/01's analysed here occurred in the spring and summer of 1997. Since J2 is far less afflicted with surface variations than J1, the new set of astrometric residuals with respect to E5, when available, will go a long way toward resolving this ambiguity.

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In the case of the other satellites, it is regrettable that no series of 3e/02 events similar to those plotted in Figs. 1a and b occurred in 1991. However, Table I does contain (multiple) observations of three 3e2 events at comparable orbital longitudes to the 1985 set. Their mean

right ascension residuals are: -0.044 (3), $+0.005$ (9) and $+0.019$ (3) and in declination: -0.013 (3), $+0.004$ (9) and $+0.008$ (3) arcsec. E5 therefore seems to provide an accurate representation for these orbits.

The final contribution in this series, now in preparation, will look more closely for evidence of secular orbital changes of the satellites from 1973 to the present.

Acknowledgments

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Erratum: In Table I of GSO (1991) the observed midtimes of the two J1 occults J3 entries of August 17, 1985 were incorrectly stated by exactly 7 hrs and should read:

mo	da	hr	mn	sec
08	17	12	[not 05]	34 43.2 and 08 17 12 34 41.1.

Figure Captions

- Fig. 1a Residuals in right ascension from the E5 ephemeris, derived from a series of eclipses [open squares] and occultations [filled ones] of Europa by Ganymede in June - Sept., 1985. All events occurred when J3's longitude lay in the range 146 ± 5 deg.
- Fig. 1b Declination residuals from E5 for the events shown in Fig. 1a. Nearly all were observed at more than one station. In both coordinates, E3 residuals differed from those of E5 by < 0.01 arc sec.
- Fig. 2a Right ascension E3 residuals given by a series of Io e/o Europa events, Aug. - Dec., 1985, with Europa at 34 ± 6 deg. Crosses correspond to a set of J2 eclipses J1 events with J2 lying near 166 deg.
- Fig. 2b Companion to Fig. 2a, with residuals from the newer, more precise E5 ephemeris.
- Fig. 3 Declination residuals from E5 for the same events. E3 residuals are negligibly different.
- Fig. 4 Longitude errors [km] of Sampson's theory as derived from the series of eclipse and occultations of Io by Europa observed from Jan. 1 - May 26, 1991. For all events Europa's orbital longitude in the range 207 ± 12 deg. Because corrections for phase defects have opposite signs for eclipses and occultations, the absence of obvious systematic effects over a range of 11 degrees in solar phase angle [cf Fig. 5a] argues that phase corrections are properly included. At the Jovian opposition distance, 100 km corresponds to 0.033 arc sec.

Figure Captions

- Fig. 5a E5 right ascension residuals obtained from the 1991 2 e/o 1 events [cf Fig. 4] and coded as in Fig. 1a. Multiply observed events yield characteristic standard errors of 0.006 and 0.009 arc sec for the eclipse and occultation residuals. Residuals from E3 are systematically offset from these by a [nearly constant] shift of -0.042 arc sec.
- Fig. 5b E5 declination residuals for the same series as Fig. 5a. The two standard errors are now 0.012 and 0.015, while the E3 residuals are systematically displaced by 0.012 arc sec. Text and Table I contain further details.
- Fig. 6a 1985 and 1991 residuals from E3, each based on about 200 light curves. Squares correspond to right ascension, triangles to declination.
- Fig. 6b Companion to Fig. 6a, now employing the E5 ephemeris. Mutual event observation are [are not] included in deriving the two ephemerides.

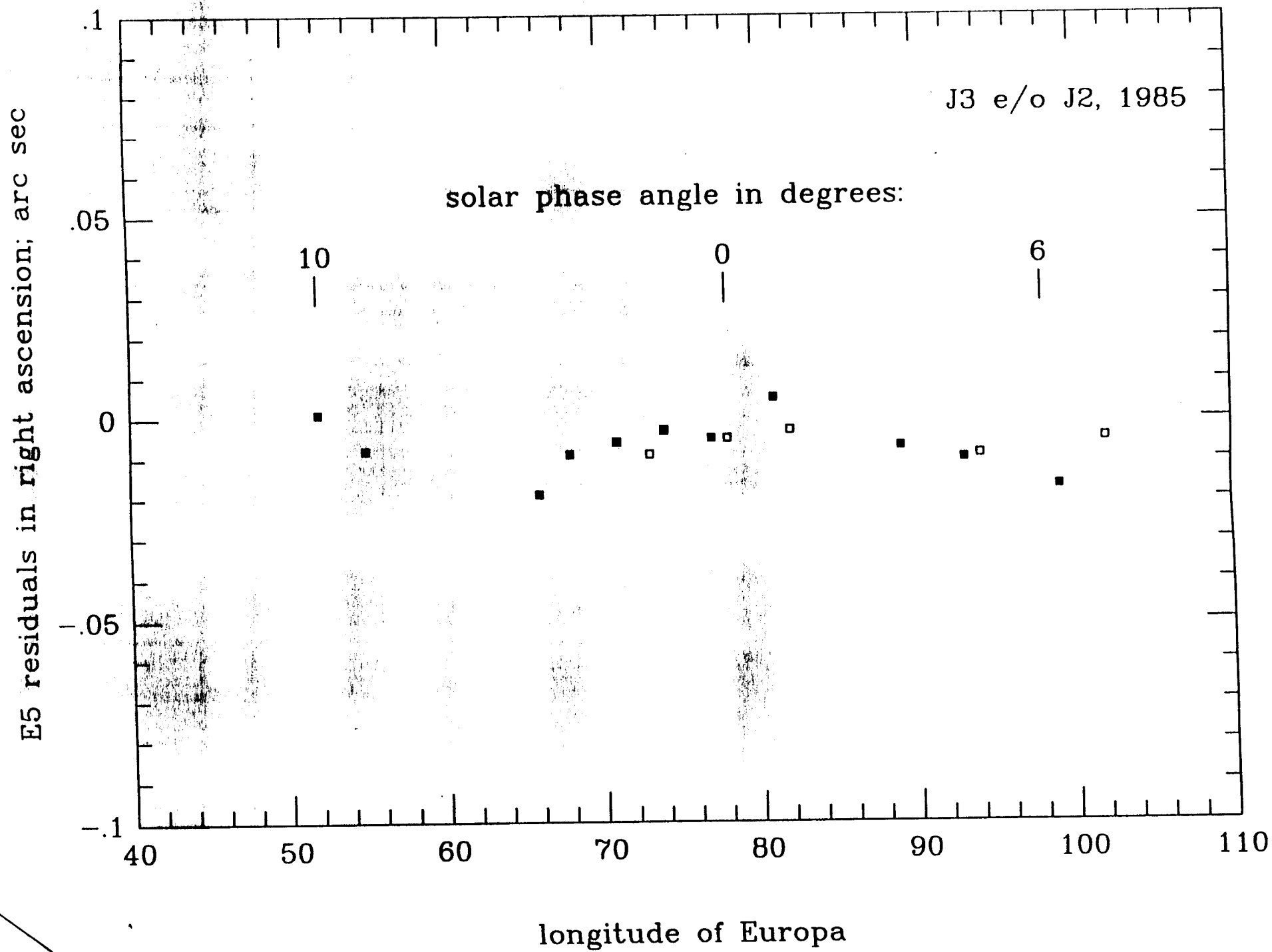
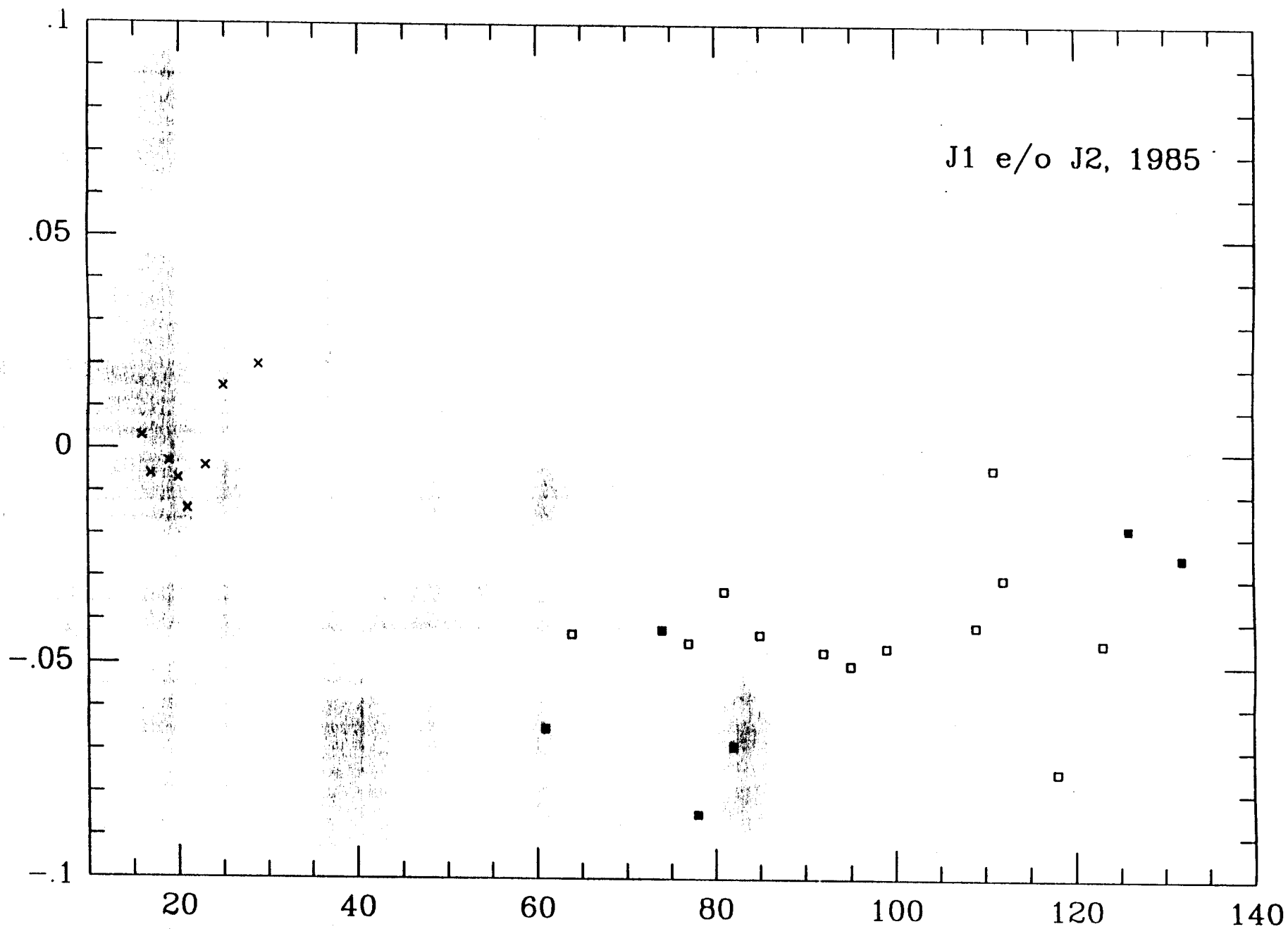


Fig. 1a

E3 residuals in right ascension, arc sec

J1 e/o J2, 1985



longitude of Io

Fig 2a

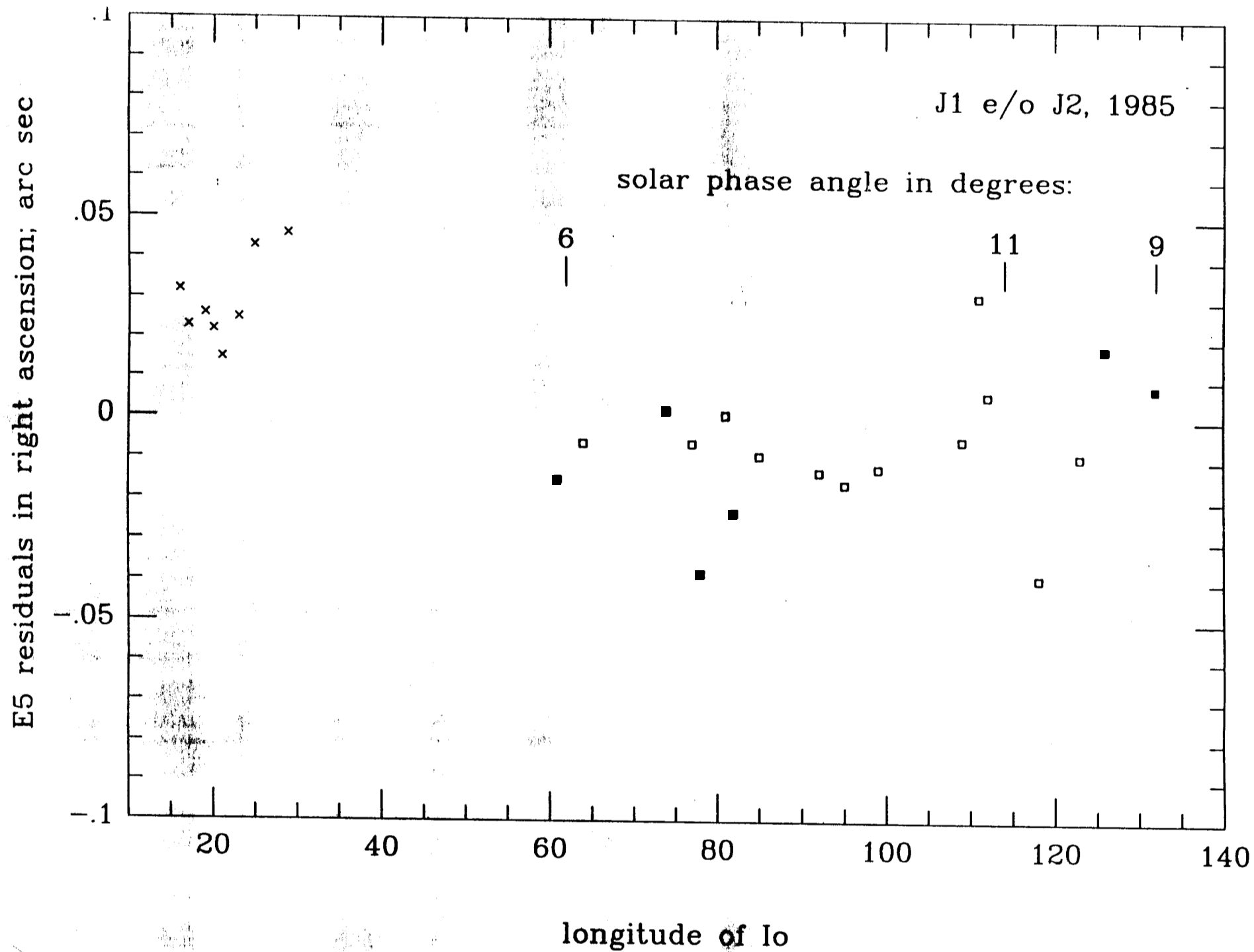


Fig 26

E5 residuals in declination; arc sec

J1 e/o J2, 1985

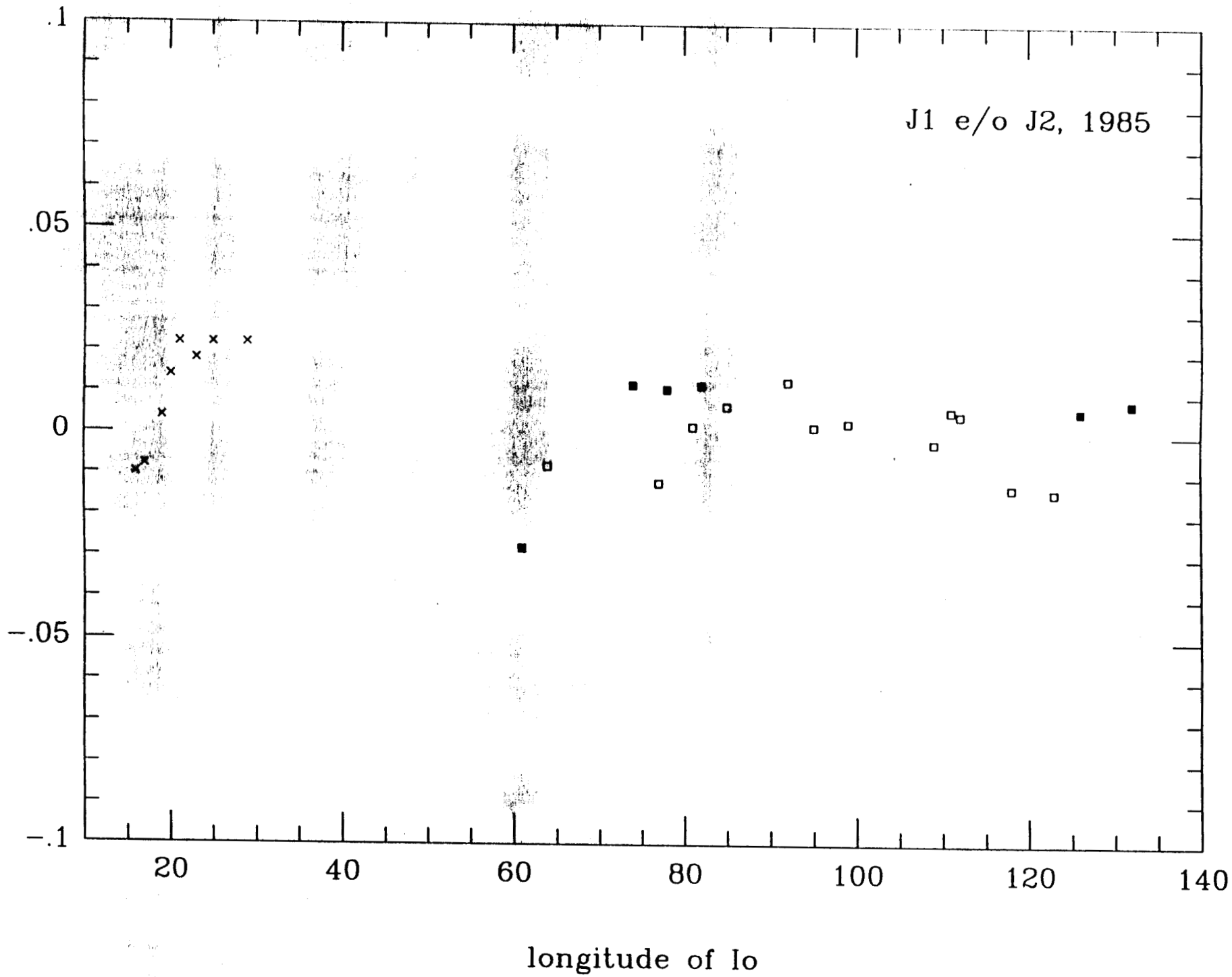


Fig. 3

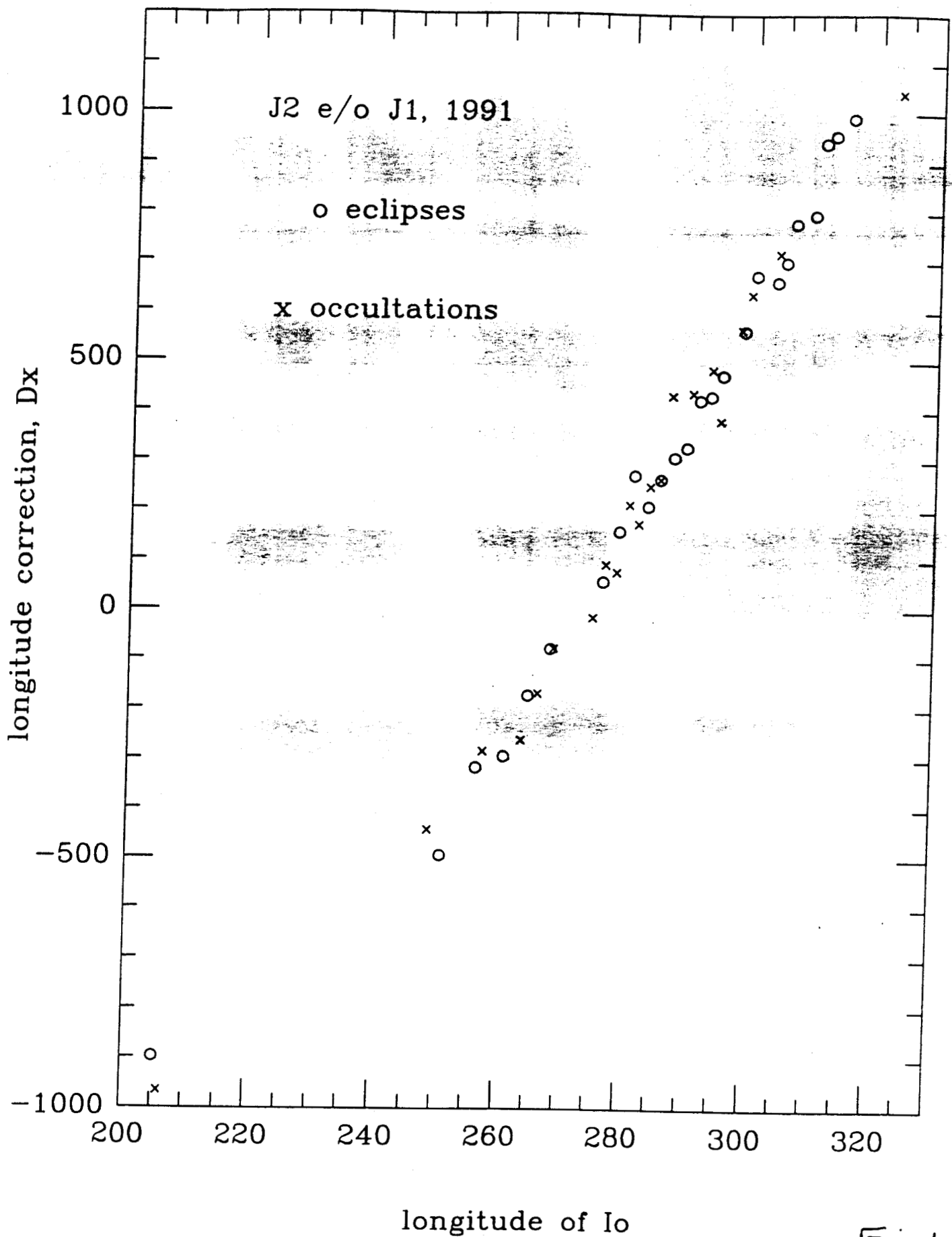


Fig. 4

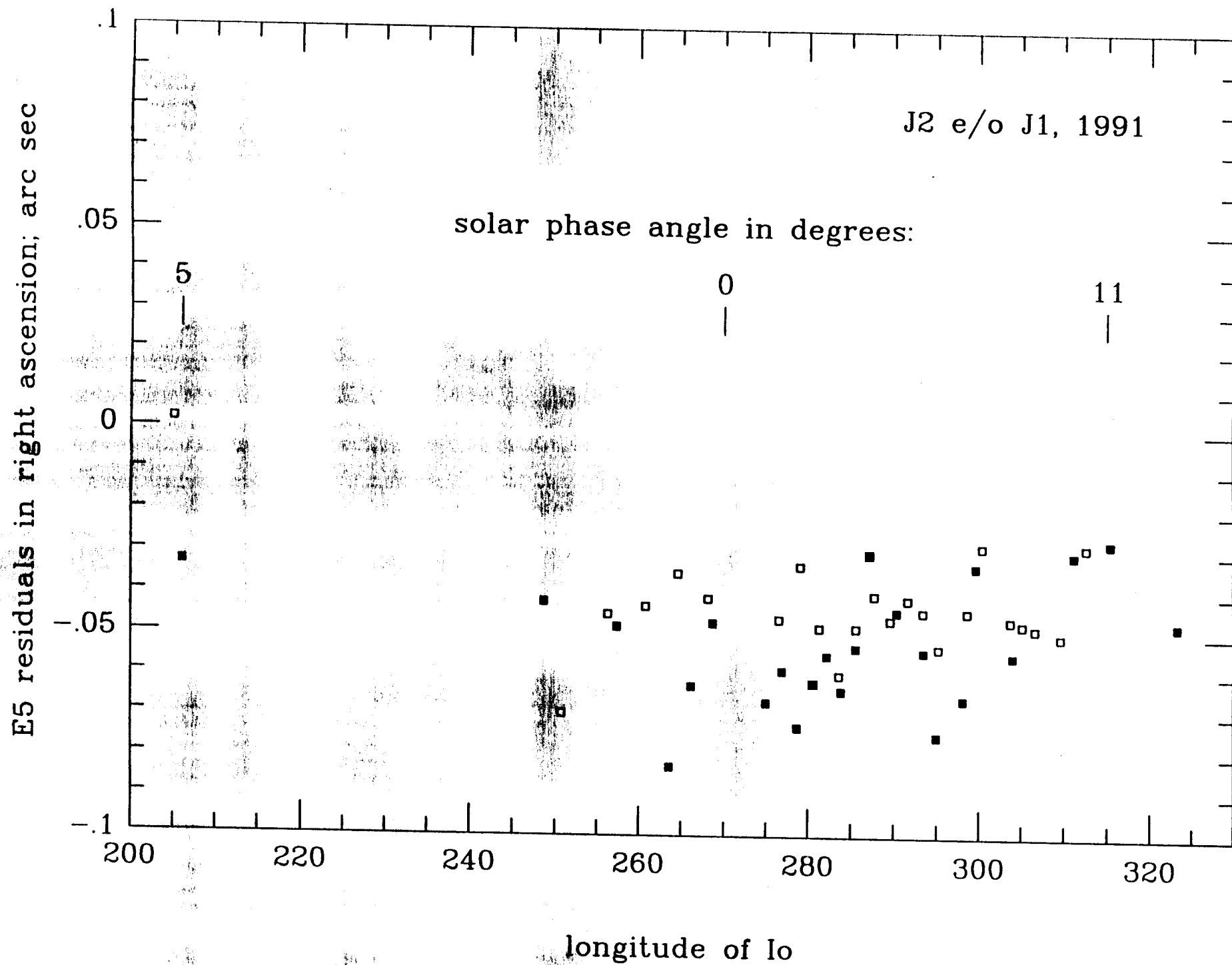
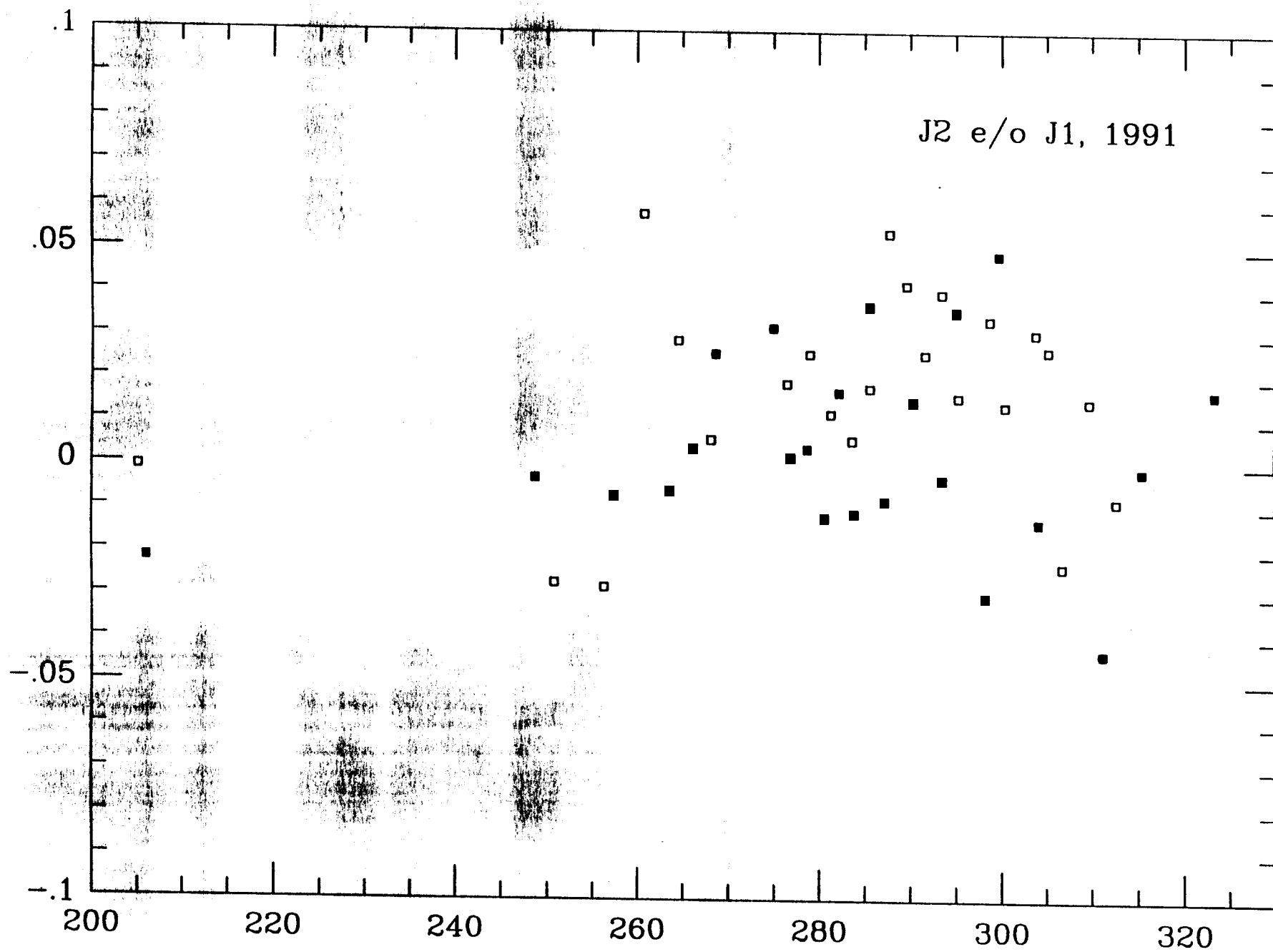


Fig. 5a

E5 residuals in declination; arc sec



longitude of Io

Fig. 5b

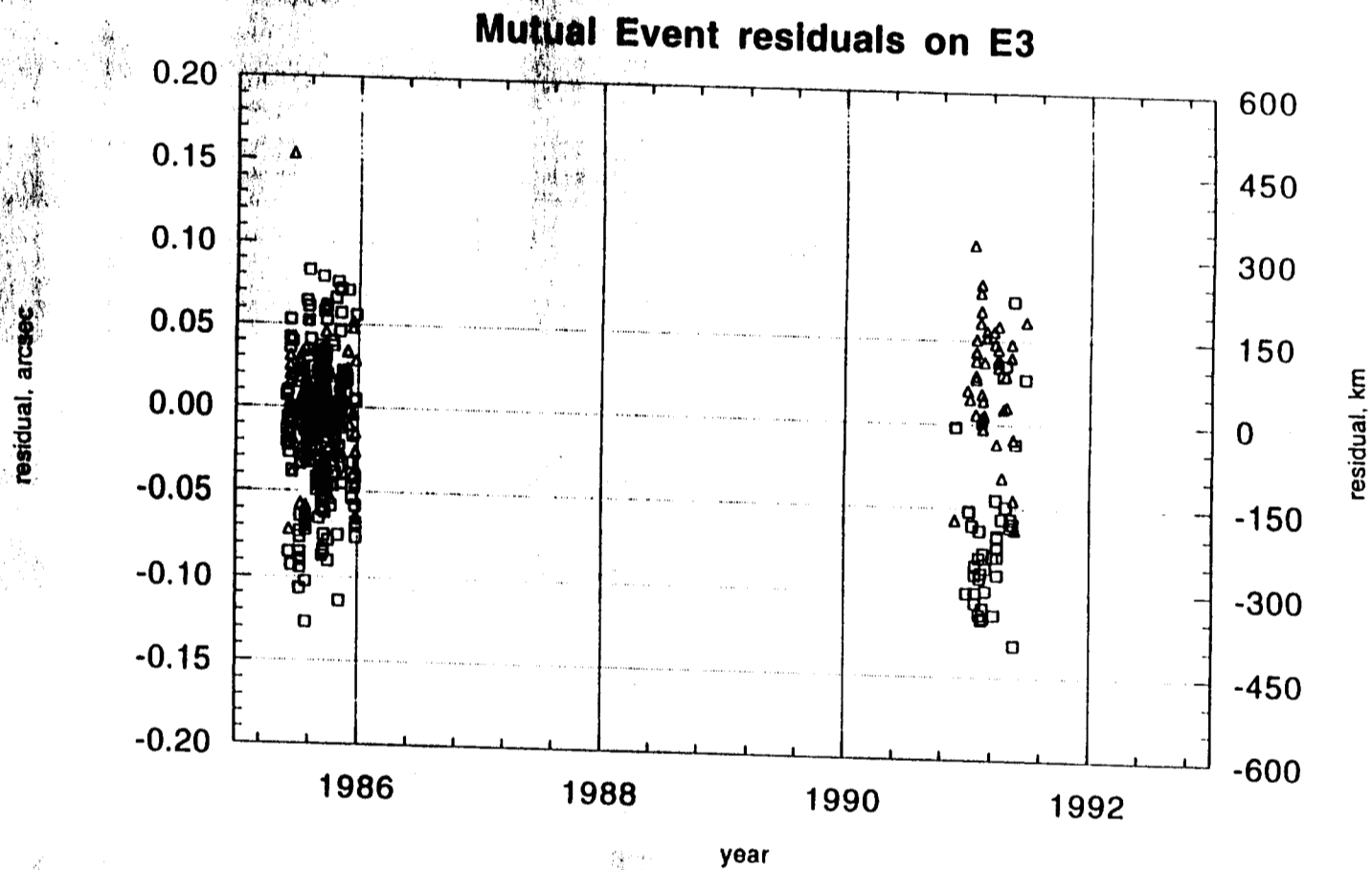


Fig. 6a

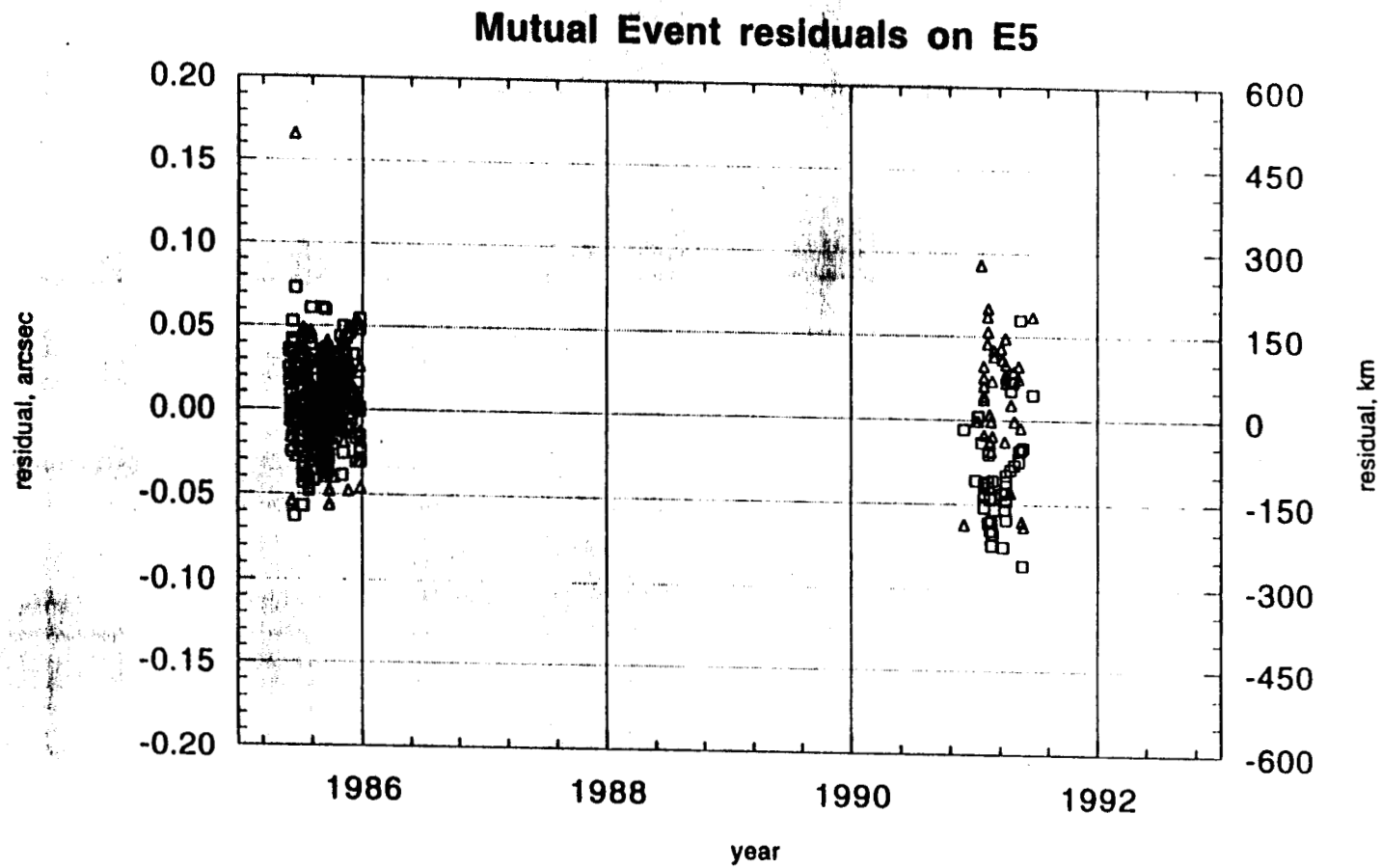


Fig. 6b

TABLE I ASTROMETRIC DATA FROM MUTUAL EVENTS IN 1991

	date	Midtime	DT	Dx	Dz	DRA	DD	JED - 2448000	PH1	PH2	W
	d m h m s	sec		km		arc	sec		deg.		
2o1.011	06 28 51.3	-27.1	-951	85	-.164	-.557	257.74518	195.8	206.1		
2o1.011	06 28 45.8	-27.4	-982	159	-.159	-.534	257.74507				
GEA2o1.051	00 20 23.7	10.8	-426	193	-.200	-.641	261.48947	215.4	248.7	1	
RGI2o1.051	00 20 29.8	11.3	-457	257	-.194	-.622	261.48954				
ORM2e1.081	07 35 42.7	21.2	-898	235	-.030	-.011	264.79190	195.2	205.1		
CAT2e1.121	01 54 45.0	-7.3	-494	132	-.024	-.044	268.55524	216.0	250.8	1	
CAT2o1.121	03 05 52.9	5.7	-227	282	-.169	-.556	268.60464	217.4	257.4		
ESO2o1.121	03 06 10.0	5.6	-342	199	-.178	-.583	268.60484				
TOK2e1.151	15 30 02.5	-5.1	-317	174	-.018	-.013	272.12151	217.2	256.3	1	
				300	-.008	-.019					
TOK2o1.181	12 00 32.4	2.3	-169	544	.345	.971	274.97608	145.3	113.8	1	
TOK2o1.181	17 25 13.2	-9.4	-997	895	.116	.345	275.20156	167.8	160.0	1	
TOK2e1.181	18 15 05.0	7.8	-988	400	.083	.326	275.23619	173.4	169.3		
BMD2e1.191	04 59 30.2	-3.1	-223	666	.027	.127	275.68372	218.0	260.8		
NIC2e1.191	04 59 40.0	-3.2	-324	701	.025	.138	275.68382				
NIC2e1.191	04 59 30.8	-3.1	-251	278	-.006	.032	275.68372			1	
TER2e1.191	04 59 39.9	-3.1	-303	360	.005	.051	275.68382			1	
CAF2e1.191	04 59 29.5	-3.1	-220	493	.015	.084	275.68370			1	
CAF2e1.191	04 59 50.2	-3.2	-385	(450)	.012	.074	275.68394				
ESO2e1.191	04 59 45.7	-3.2	-350	566	.020	.103	275.68389				
ESO2o1.191	05 33 58.8	2.8	-262	242	-.149	-.490	275.70765	218.3	263.6	1	
GEA2e1.221	18 23 16.6	-1.8	-194	(400)	.015	.071	279.24193	218.4	264.6		
CAF2e1.221	18 23 12.0	-1.8	-159	765	.041	.162	279.24188			1	
KAV2e1.221	18 23 12.3	-1.8	-160	275	.005	.039	279.24188				
OHP2e1.221	18 23 14.4	-1.8	-179	239	.002	.031	279.24191				
KAV2o1.221	18 43 54.8	1.7	-198	331	-.130	-.415	279.25625	218.5	266.2		
NIC2o1.221	18 43 54.2	1.7	-189	308	-.129	-.422	279.25626			1	
OHP2o1.221	18 43 41.2	1.7	-65	264	-.133	-.436	279.25611				
TER2o1.221	18 43 56.9	1.7	-219	295	-.130	-.426	279.25629				
ORM2o1.261	07 53 09.9	0.7	-66	374	-.106	-.350	282.80438	218.6	268.7		
BMD2o1.261	07 53 10.2	0.7	-69	389	-.105	-.345	282.80438				
PRI2o1.261	07 53 12.9	0.7	-98	406	-.103	-.340	282.80441				
ORM2e1.261	07 44 49.7	-0.7	-84	369	.018	.071	282.79859	218.6	268.1	1	
BMD2e1.261	07 44 49.6	-0.7	-76	363	.019	.069	282.79859				
PRI2e1.261	07 44 48.8	-0.7	-76	281	.011	.049	282.79858				
HAN2o1.052	23 13 36.1	-1.7	-20	522	-.047	-.127	293.44351	218.5	275.0		
OHP2o1.052	23 13 33.3	-1.7	14	544	-.045	-.121	293.44348				

	Date	Midtime	DT	Dx	Dz	DRA	DD	JED - 2448000	PH1	PH2	W	
1.052	23	13	38.4	-1.7	-48	417	-.056	-.159	293.44354	218.5	275.0	1
1.052	23	13	39.4	-1.7	-61	547	-.045	-.120	293.44355			
1.052	23	13	33.7	-1.7	58	(400)	-.042	-.170	293.44348			
2.052	23	13	37.3	-1.7	-35	133	-.082	-.247	293.44352			
HAN2e1.052	23	36	28.1	1.6	28	(520)	.045	.104	293.45942	218.4	276.5	1
GEA2e1.052	23	36	30.2	1.6	21	252	.017	.040	293.45941			1.
GEA2e1.052	23	36	23.9	1.6	81	378	.026	.071	293.45934			1.
BSP2e1.052	23	36	23.9	1.6	80	897	.066	.200	293.45934			1
GEA2e1.052	23	36	21.4	1.6	104	487	.032	.099	293.45931			1
OHP2e1.052	23	36	23.7	1.6	84	324	.022	.058	293.45934			2
GEA2e1.052	23	36	29.2	1.6	24	489	.035	.099	293.45940			1.
KAK2o1.092	12	19	30.5	-2.3	90	409	-.040	-.098	296.98921	218.4	276.9	2
BNZ2o1.092	12	19	30.3	-2.3	92	572	-.047	-.127	296.98921			1.
KAK2e1.092	12	51	31.8	2.2	136	372	.026	.063	297.01145	218.2	279.0	1.
BNZ2e1.092	12	51	28.8	2.2	178	(570)	.045	.104	297.01141			1
NIC2o1.132	01	24	28.7	-2.9	69	331	-.030	-.055	300.53424	218.2	278.7	1.
NIC2o1.132	01	24	31.6	-2.9	29	265	-.036	-.075	300.53427			1.
PIC2o1.132	01	24	26.1	-2.8	104	425	-.022	-.026	300.53421			2
GEA2o1.132	01	24	31.7	-2.8	28	(400)	-.024	-.034	300.53427			1.
OHP2o1.132	01	24	25.8	-2.8	107	(400)	-.024	-.034	300.53420			1
ESO2o1.132	01	24	28.4	-2.8	76	(400)	-.025	-.036	300.53423			1.
ORM2o1.132	01	24	25.5	-2.8	117	320	-.030	-.059	300.53420			1.
LOW2e1.132	02	05	04.8	2.7	203	304	.019	.036	300.56244	217.9	281.3	1.
NIC2e1.132	02	05	06.9	2.7	175	445	.032	.071	300.56246			1.
PIC2e1.132	02	05	06.5	2.7	193	340	.023	.045	300.56244			1.
GEA2e1.132	02	05	10.9	2.7	118	482	.034	.080	300.56250			2
ESO2e1.132	02	05	08.8	2.7	147	446	.032	.071	300.56248			2
BMD2e1.132	02	05	06.5	2.7	182	363	.025	.051	300.56245			2
KAV2o1.162	14	29	42.3	-3.3	170	354	-.011	.019	304.07942	218.0	280.6	2
VIA2o1.162	14	29	39.0	-3.3	211	325	-.020	.011	304.07937			1
VIA2e1.162	15	18	35.5	3.1	181	325	.013	.031	304.11335	217.6	283.6	1
KAV2e1.162	15	18	31.8	3.1	233	405	.027	.049	304.11333			2
OHP2e1.202	04	31	03.5	3.6		314			307.66364	217.2	285.7	
ESO2e1.202	04	30	49.2	3.6	226	(400)	.024	.031	307.66340	217.2	285.6	1
LOW2e1.202	04	30	44.6	3.5	298	460	.029	.046	307.66334			1.
LOW2o1.202	03	34	14.3	-3.8	196	350	.005	.086	307.62411	217.8	282.2	1.
PIC2o1.202	03	34	12.8	-3.8	210	549	.023	.147	307.62409			1.
ESO2o1.202	03	34	25.0	-3.8	35	(400)	.009	.100	307.62423			1
RIO2o1.202	03	34	12.0	-3.8	221	658	.031	.178	307.62408			1.
BOR2o1.202	03	34	13.0	-3.8	206	247	.000	.056	307.62409			1
MEU2o1.202	03	34	15.9	-3.8	165	(400)	.010	.102	307.62413			1
KAV2o1.232	16	39	15.2	-4.2	248	361	.023	.158	311.16910	217.5	283.9	2

Table I [

date	Midtime	DT	Dx	Dz	DRA	DD	JED - 2448000	PH1	PH2	Wc
e1.232	17 42 58.7	3.9	317	613	.037	.066	311.21336	216.7	287.7	1.
e1.232	17 43 00.1	3.9	295	531	.031	.045	311.21337			1.
MD2o1.272	05 43 45.6	-4.6	262	528	.054	.276	314.71373	217.2	285.6	2
BMD2e1.272	06 54 16.2	4.2	326	(530)	.026	.023	314.76269	216.3	289.6	1.
CNR2o1.023	18 48 38.5	-4.9	441	492	.067	.330	318.25860	216.8	287.2	1.
NIC2o1.023	18 48 39.7	-4.9	421	349	.054	.288	318.25861			1
GEA2e1.023	20 05 35.4	4.5	301	(500)	.018	-.008	318.31203	215.8	291.6	1
DAC2e1.023	20 05 27.1	4.5	446	492	.018	-.010	318.31193			2
NIC2e1.023	20 05 34.9	4.5	310	(500)	.018	-.008	318.31202			1.
NIC2e1.023	20 05 26.4	4.5	459	399	.010	-.033	318.31192			2
CAF2e1.023	20 05 25.0	4.5	482	(500)	.018	-.008	318.31191			1.
MEU2e1.023	20 05 22.1	4.5	534	(500)	.018	-.008	318.31187			1
TOK2e1.063	09 15 57.6	4.8	471	566	.017	-.018	321.86069	215.3	293.4	1
TOK2e1.063	09 16 02.7	4.8	390	(500)	.012	-.034	321.86075			1
CAT2o1.093	20 58 29.9	-5.2	539	637	.108	.497	325.34834	216.1	290.4	1
GEA2o1.093	20 58 35.3	-5.2	448	593	.105	.484	325.34840			2
KAV2o1.093	20 58 37.7	-5.2	403	524	.100	.464	325.34843			2
PAR2o1.093	20 58 40.6	-5.3	360	288	.079	.396	325.34846			1.
TER2o1.093	20 58 36.2	-5.3	432	441	.092	.440	325.34841			2
TER2e1.093	22 26 31.9	4.9	462	350	-.008	-.099	325.40947	214.7	295.2	1.5
BOR2e1.093	22 26 31.5	4.9	468	430	-.001	-.080	325.40947			1.5
OHP2e1.093	22 26 34.8	4.9	408	505	.005	-.061	325.40951			1
PAR2e1.093	22 26 28.5	4.9	526	(430)	-.002	-.080	325.40943			1
MEU2e1.093	22 26 29.9	4.9	497	458	.000	-.073	325.49045			1.5
BRB2o1.163	23 09 14.2	-5.2	439	564	.131	.586	332.43864	215.2	293.5	2
ESS2o1.163	23 09 09.7	-5.4	529	327	.111	.520	332.43859			1.5
BMD2e1.173	00 46 22.0	5.2	551	548	-.010	-.114	332.50608	213.6	298.6	2
PIC2e1.173	00 46 19.9	5.2	590	540	-.011	-.116	332.50606			1.5
NIC2e1.173	00 46 18.9	5.2	598	563	-.011	-.110	332.50605			1.5
NIC2e1.173	00 46 19.0	5.3	594	381	-.026	-.155	332.50605			1.5
RIO2e1.173	00 46 21.7	5.2	553	594	-.006	-.103	332.50608			1.5
HNY2e1.173	00 46 25.9	5.3	475	418	-.020	-.146	332.50613			1
ESS2e1.173	00 46 21.3	5.2	561	(570)	-.008	-.108	332.50608			1
VIA2o1.203	12 14 45.4	-5.0	381	(570)	.151	.634	335.98389	214.7	295.0	1
SSA2e1.203	13 55 40.5	5.4	692	304	-.040	-.210	336.05395	213.0	300.3	1.5
KAV2e1.203	13 55 42.7	5.4	651	630	-.014	-.130	336.05398			1.5
KAV2o1.273	14 26 37.2	-4.9	563	369	.152	.666	343.07488	213.8	298.1	1.5
KAV2e1.273	16 14 12.2	5.6	660	508	-.047	-.236	343.14958	211.8	303.7	2
BMD2o1.313	03 33 05.2	-3.6	633	669	.194	.783	346.62075	213.2	299.6	1.5

	Date	Midtime	DT	Dx	Dz	DRA	DD	JED - 2448000	PH1	PH2	Wg
	1.313	05 23 13.4	5.6	734	492	-.060	-.280	346.69721	211.1	305.1	1.
	1.313	05 23 15.1	5.6	693	488	-.062	-.281	346.69724			2
	1.313	05 23 13.8	5.6	721	474	-.064	-.284	346.69722			2
	1.313	05 23 17.3	5.6	649	497	-.061	-.279	346.69726			1.
	2e1.034	18 31 50.0	5.4	814	186	-.102	-.398	350.24456	210.4	306.6	1
	AV2e1.034	18 31 52.4	5.5	757	340	-.089	-.360	350.24459			2
	3EL2e1.034	18 31 52.2	5.0	762	(400)	-.084	-.346	350.24458			1
	TER2o1.104	18 53 34.0	-3.3	717	450	.197	.799	357.25903	211.5	304.0	1
	TER2e1.104	20 48 53.3	5.4	834	591	-.099	-.389	357.33911	209.1	309.6	1.
	TMR2e1.104	20 48 54.4	5.5	808	634	-.095	-.379	357.33912			1
	GEA2e1.104	20 48 55.8	5.3	779	349	-.120	-.448	357.33914			2
	OHP2e1.104	20 48 54.7	5.3	804	402	-.115	-.435	357.33912			1.5
	BOR2e1.104	20 48 54.8	5.3	804	395	-.116	-.437	357.33912			2
	HEG2e1.104	20 48 55.1	5.3	796	415	-.114	-.432	357.33913			1.5
	ESS2e1.104	20 48 57.5	5.2	742	322	-.122	-.455	357.33916			2
	VIA2e1.144	09 57 12.8	4.9	941	256	-.138	-.521	360.88625	208.4	311.1	1
	BOR2e1.174	23 05 19.1	4.8	956	378	-.154	-.537	364.43320	207.7	312.6	1
	OHP2e1.174	23 05 19.1	4.8	957	394	-.153	-.533	364.43320			1
	BMD2e1.254	01 21 17.0	4.0	991	465	-.186	-.632	371.52700	206.3	315.4	1.5
	RIO2o1.265	21 46 32.8	-3.5	1041	567	.151	.576	403.37501	202.2	323.3	2
	MEU1e2.224	18 57 04.2	4.3	1551	303	.092	.172	369.26036	215.4	338.5	1.5
	BRB1e2.294	21 11 40.5	4.3	1476	(330)	.053	.062	376.35318	218.1	337.0	1.5
	OHP1e2.294	21 11 37.9	4.3	1545	(330)	.053	.061	376.35315			1.5
	NIC1e2.294	21 11 39.0	4.3	1515	(330)	.053	.062	376.35317			1.5
	NIC1e2.294	21 11 43.0	4.3	1410	(330)	.053	.061	376.35321			1.5
	DNC1e2.145	01 41 46.0	4.4	1590	434	-.019	-.137	390.53946	223.4	334.4	1
	ESO1e2.065	23 26 28.1	4.4	1624	(330)	.013	-.051	383.44614	220.9	335.5	1
	BOR1e2.065	23 26 34.1	4.4	1474	(330)	.013	-.051	383.44621			1.5
	KAV1e2.175	14 49 41.8	4.4	1428	355	-.044	-.205	394.08632	225.1	333.4	2
	MEU1e2.245	17 05 37.4	4.4	1405	(330)	-.084	-.310	401.18011	227.9	331.9	1.5
	KAK4e2.013	16 30 52.8	12.9	1352	529	.199	.555	317.16299	159.3	101.0	1.5
	KAV4e2.183	19 43 25.4	4.7	1843	259	.270	.740	334.29558	167.6	36.9	2
	PIC4e2.183	19 43 14.1	4.7	1999	106	.244	.707	334.29545			1.5
	BER4e2.183	19 43 34.0	4.7	1683	267	.272	.742	334.29588			1
	OHP4e2.183	19 43 30.9	4.3	1746				334.29558			
	TER4e2.183	19 43 15.4	4.6	2033	460	.286	.790	334.29546			2
	CAF4e2.183	19 43 25.1	4.6	1851	423	.283	.781	334.29557			2
	GEA4e2.183	19 43 22.1	4.6	1905	271	.271	.743	334.29554			2
	OHP4e2.183	19 43 24.5	4.6	1861	415	.283	.779	334.29557			1.5
	CAF4e2.183	19 43 24.4	4.6	1864	423	.283	.781	334.29556			2

date Midtime DT Dx Dz DRA DD JED - PH1 PH2 W
2448000

2e4.103	03 44 22.9	7.8	326					325.63019	237.0	342.6	
CAF2e4.294	22 17 51.4	-34.9	136					376.39914	341.7	353.6	
ZNL3e4.154	01 34 16.1	19.4	224					361.53691	101.1	33.6	
ORM3e4.165	00 55 29.8	10.3	493	-116	.123	.218		392.50715	217.1	339.9	
MEU4e3.204	23 13 08.5	8.1	-137	-411	.487	1.312		367.43836	159.8	37.3	
CAF3e1.075	20 29 08.9	5.1	114	260	.270	.672		384.32292	165.9	38.2	1
CAF3e1.075	20 29 08.6	5.2	121	175	.263	.651		384.32292			1
NIC3e1.075	20 29 09.9	5.2	90	208	.266	.659		384.32293			2
NIC3e1.075	20 29 08.4	5.2	125	182	.264	.653		384.32292			2
OHP3e1.075	20 29 06.9	5.2	162	229	.268	.664		384.32290			1
CAT3e1.075	20 29 07.0	5.2	160	250	.270	.669		384.32290			2
BOR3e1.075	20 29 05.7	5.1	191	287	.272	.678		384.32289			2
GEA3e1.145	23 20 08.0	5.7	35	-9	.176	.397		391.44102	163.5	46.2	1
GEA3e1.225	02 15 28.9	6.0	117	(200)	.127	.258		398.56218	161.3	54.8	1
ORM3e1.225	02 15 36.9	6.1	-44	(200)	.127	.258		398.56227			1
OHP3e1.276	16 43 54.9	3.2	310					435.16260	200.0	299.4	
OHP3e1.047	19 42 36.9	3.3	201					442.28631	197.9	308.4	
ORM4e1.085	01 25 11.0	12.0	1568	102	-.105	-.413		384.52848	167.2	80.3	2
BMD4e1.085	01 25 11.8	12.0	1558	66	-.108	-.422		384.52849			2
GEA2o3.13n	01 47 31.5	9.5	200	248	.288	.842		208.54619	247.0	324.4	1
PIC2o3.13n	01 47 38.7	9.3	209	222	.312	.826		208.54627			1
TER2o3.20n	05 10 15.2	12.6	211	209	.238	.565		215.68761	250.5	323.4	1
OHP2o3.20n	05 10 22.9	13.1	103	-61	.216	.493		215.68769			1
GEA2o3.20n	05 10 01.9	12.6	392	233	.240	.571		215.68745			1
SFC2o3.27n	08 32 10.4	14.1	347	-99	.139	.260		222.82844	254.2	322.6	1
TMR2o3.25d	22 06 59.7	14.5	157	-35	-.034	-.235		251.39634	270.8	321.1	1
PIC2o3.021	01 39 37.3	14.0	232	116	-.032	-.220		258.54436	276.0	321.4	1
CAT2o3.021	01 39 04.6	13.7	461	-174	-.060	-.306		258.54398			1
GEA2o3.021	01 39 10.3	12.3	431	-247	-.071	-.326		258.54403			1
ESO2o3.091	05 24 32.6	13.2	375	222	-.021	-.171		265.70084	282.4	322.3	1
SSA2o3.29m	10 08 23.5	68.2	-487	58	-.141	-.185		710.89694	30.5	18.4	1
PIC2e3.011	22 53 10.2	-8.8	344	15	.196	.744		258.42877	269.8	321.1	1
GEA2e3.011	22 53 18.1	-9.3	282	-111	.186	.712		258.42886			1
CAT2e3.091	03 03 06.4	-9.6	222	2	.142	.545		265.60262	276.5	321.5	1

Date	Midtime	DT	Dx	Dz	DRA	DD	JED - 2448000	PH1	PH2	W
13.161	07 42 42.5	-9.0	306	140	.121	.444	272.79699	285.2	322.9	
2e3.231	14 04 12.1	-9.7	246	-115	.134	.407	280.06203	301.4	327.9	1
K2e3.231	14 04 26.2	-9.6	212	11	.142	.440	280.06219			
BOR2e3.166	20 43 42.6	6.0	-241	52	-.097	-.361	424.32980	154.8	15.4	1
MKH2e3.22m	08 57 38.0	-54.5	-479	100	-.060	-.124	703.84811	30.7	18.5	1
RCI3e2.253	19 42 18.0	3.5	-368	363	.345	.968	341.29425	164.2	25.8	2
TMR3e2.253	19 42 17.1	3.6	-354	300	.339	.953	341.29424			1
HAN3e2.253	19 42 19.1	3.5	-394	324	.340	.959	341.29422			1
CAF3e2.014	22 56 25.5	4.4	-159	487	.265	.705	348.42846	162.6	28.5	1
GEA3e2.014	22 56 33.9	4.4	-347	473	.264	.701	348.42856			2
GEA3e2.014	22 56 25.3	4.4	-154	484	.265	.704	348.42846			1
CAF3e2.014	22 56 26.7	4.5	-186	404	.258	.684	348.42847			2
CAF3e2.014	22 56 27.3	4.5	-201	337	.253	.668	348.42848			2
OHP3e2.014	22 56 31.8	4.0	-300	445	.261	.694	348.42853			1
BOR3e2.014	22 56 27.7	4.4	-209	467	.263	.700	348.42849			2
TER3e2.014	22 56 26.3	4.4	-176	504	.266	.709	348.42847			1
PAR3e2.014	22 56 36.0	4.6	-398	231	.244	.641	348.42858			1
MKH3e2.164	05 26 54.6	5.2	-332	(400)	.076	.124	362.69836	159.5	33.9	1
DAC3e2.164	05 26 54.4	5.2	-332	(400)	.073	.124	362.69835			1
TPK3e2.164	05 26 51.8	5.2	-275	(400)	.073	.124	362.69832			1
MKH3e2.234	08 42 47.4	5.4	-329	451	-.013	-.126	369.83372	158.0	36.6	1
VIA3o2.196	08 28 24.2	-4.6	-610	478	.029	.149	426.81900	148.5	55.8	1

Observatory Code; Locations

ESO: European Southern Obs. Chile	BNZ: Adams Obs. Blenheim N. Zealand
BMD: Bowie Maryland USA	LOW: Lowell Obs. Flagstaff Ariz. US
GEA: Grup d'Estuds Astron. No. Spain	VIA: Victoria NSW Australia
RCI: Reggio Calabria Italy	PIC: Pic du Midi France
ORM: Oak Ridge Obs. Mass. USA	RIO: Rio de Janeiro Brazil
CAT: Catania Astrophys. Obs. Sicily	BOR: Bordeaux Univ. Obs. France
TOK: Tokyo Obs. Japan	MEU: Meudon Obs. France
NIC: Nice Obs. France	CNR: Cluj-Napoca Obs. Romania
TER: Collurania Obs. Teramo Italy	SSA: Siding Spring Obs. Australia
CAF: Calern, Cote d'Azur France	MKH: Mauna Kea, Hawaii
KAV: Vainu Bappu Obs. Kavalur India	TOC: Toronto Ontario Canada
PRI: Providence Rhode Island USA	BRB: Brasopolis Brazil
HAN: Harastua Norway	DNC: Durham North Carolina USA
OHP: Obs. Haute-Provence France	BER: Berlin Germany
PAR: Paris Obs. France	HEG: Heuweiler Germany
BSP: Barcelona Spain	ESS: Essen Germany
KAK: Kakuda Japan	HNY: Holtsville New York USA
ZNL: Zoetermeer Netherlands	TMR: Timisoara Romania
SFC: San Francisco Cal. USA	TPK: Topeka Kansas USA
DAC: Devon Ast. Obs. Alberta Canada	BEL: Belgrade Obs. Serbia